API 571 Reference Card

Corrosion Mechanism	Description	Affected Unit or Equipment	Temp. Range in °F	Affected metallurgy	Prevention	Inspection Methods
	GENERAL CORROSION MECHANISMS-MECHANICAL AND METALLURGICAL FAILURE MECHANISMS					
Graphitization	Loss in strength, ductility, creep resistance	• Primary hot wall piping & Equipment in FCC, Catalytic reformer and Coker Units • Coarse Pearlitic grades when compare to Bainitc grades	800-1100	CS & .5Mo steel	Adding Cr +.7	Metallographic test *
Spheroidization/ Softening	Loss in strength, creep resistance- large agglomerated arbides in 5-9% Cr	• Hot wall piping & Equipment in FCC, Catalytic reformer and Coker Units • Fired heaters or boilers also may affect	850-1400	CS, Cr-Mo	Temperature control	MG, Tensile and hardness tests.
Temper Embrittlement.	Reduction in toughness- limited P to 25% of max design P for temp's below MPT(350 °F for older steel and 150°F for newer steels)	• Equipment in Hydro processing units particularly reactors, hot feed/ effluent exchanger components and hot HP separators • Other units include CRUs, FCC Reactors, Coker and Vis-breaking units • Welds are more susceptible than the base metal	650-1100	2.25Cr-1Mo	New -Limit impurities* Si, Mn, P, Sn, Sb, As)	Charpy Impact
Strain Aging	Increase in hardness and strength with a reduction in ductility and toughness.	• Any heavy wall thickness equipment manufactured from susceptible materials and has not been stress relieved.	-	CS & C-.5 Mo	Adding aluminum and PWHT	No*
885˚F Embrittlement	Loss in toughness due to a metallurgical change caused by high temp.	• Fractionator trays & Internals in High temperature vessels in FCC, Crude, Vacuum and Coker Units • Upset tower trays of materials type 409 & 410 while bending/ welding. • DSS heat exchanger tubes.	600-1000	400SS series, duplex SS, wrought and cast 300 series SS	Use of low ferrite or non-ferritic alloys* Use of PWHT followed by rapid cooling	Impact or bend test Hardness *
Sigma Phase Embrittlement	Loss of fracture toughness	• SS cyclones, Piping duct work, Valves in High temperature FCC Regenerator service. • 300 Series SS weld overlays, Tube-Tube sheet attachment welds during PWHT • SS Heater tubes	1000-1750	Duplex, Ferritic & martensitic, with Cr> 17%,300 SS wrought ,cast ,weld	use alloys that are resistant to sigma formations *Desigmatized by solution annealing@1950/4 hrs	Physical Testing*
Brittle Fracture	Cracks are straight, non-branching with no plastic deformation	• Equipment manufactured prior to ASME Sec VIII Div.1 Dec 1987 addenda. • Thick wall equipment during start-up, shut down or hydro test/ tightness testing.	--	CS, LAS, 400 SS	Design for low temp operation *	N/A
Creep & Stress Rupture	Increase of 25 F or 15% stress can cut the remaining life in half, Deformation/cracking	• Heater tubes in fired heaters, tube supports, hangers, and other furnace internals. • Piping & Equipment in or near creep range- 1. Hot-wall catalytic reforming reactors and furnace tubes, 2. Hydrogen reforming furnace tubes, 3. Hot wall FCC reactors, 4. FCC main fractionator, 5. Regenerator internals. • Weld HAZ at nozzles, High stress areas on catalytic reformer reactors • Welds joining dissimilar metals due to differential thermal expansion	--	All	PWHT	UT,RT,ET,VT,WFMT,SWUT, PT
Thermal Fatigue	Thermal fatigue is the result of cyclic stresses caused by variations in temperature. Transgranular cracks filled with oxides.	• Mix points of hot and cold streams such as hydrogen mix points in Hydro processing units, Where condensate comes in contact with steam systems (Attemporators) • Coke drum shells • Coke drum skirts • In Steam generating equipment- The rigid attachment between super heaters and re-heaters • Tubes in High temp. SH and RH penetrating through the cooler water wall tubes • Steam actuated soot blowers	Temp. swing of 200F	All	Design & operation to minimize thermal stress & cycling *	VT,PT,MT *
Short Term Overheating – Stress Rupture	Permanent deformation occurring at relatively low stress levels as a result of localized overheating. "fish mouth" failures.	• All boiler and fired heater tubes • Furnaces with coking tendencies-Crude, Vacuum, Heavy oil hydro processing and coker units, • Hydro processing reactors • Refractory lined equipment in FCC, Sulfur plant, and other units that may suffer localized overheating.		All	Burner management, Minimize localized temperature excursions.	VT,IR, Heat indicating paint

API 571 Reference Card

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Steam blanketing	Departure from nucleate boiling (DNB) - near knife edge with elongation of grains.	• All SG equipment-Fired heaters, Waste heat ex. In sulfur plants, Hydrogen reformers and FCC units. • Can occur in SH, RH during start up when condensate blocks steam flow.	--	CS, LAS	Design	VT, IR scans
DMW Cracking	Occurs on ferrtic side of weld@ high temp. between austenitic and ferrtic	• Welds used to join clad pipe in locations such as transitions in Hydro processing reactor O/L piping • Hydro processor exchanger I/L and O/L piping • Alloy transitions inside Fired heaters • All areas where the welds are done between Ferritic materials and Austenitic materials	>510	Ferrtic & austenitic	Use nickel base filler	VT,PT,MT
Thermal Shock	Thermal fatigue cracking, when high and non-uniform thermal stress develop over a short time due to differential expansion or contraction. Usually occurs when a colder liquid contacts a warmer metal surface. Craze cracks	• FCC, Cokers, Catalytic reforming and high severity hydro processing units • High temperature equipment and piping in any unit • Materials that have lost ductility, such as Cr-Mo equipment(Temp.Embrittlement) • Equipment subjected to accelerated cooling procedures to minimize shutdown	-	All	Prevent interruption in flow of high temp line. Minimize severe restraint. Install thermal sleeves Review hot/cold injection points	PT/MT, difficult to locate
Erosion/Corrosion	Pits, groves, waves, rounded holes and valleys(directional pattern)	• All equipment and piping exposed to moving fluids and/ or catalysts. • Piping systems particularly Bends, elbows, tees, reducers, downstream of letdown valves and block valves, pumps, impellers, agitators, agitated vessels, heat exchanger tubing, measuring device orifices, turbine blades, nozzles, ducts and vapor lines, scrapers, cutters, wear plates, equipment carrying slurries. • HP reactor effluent piping- Due to Ammonium Bisulfide • Crude and vacuum unit piping and vessels-Exposed to naphthenic acid in some crude oils.	-	All	More corrosion resistant alloy *	VT,UT,RT
Cavitation	Sharp-edge pitting damage	• Pump casings • Pump Impellers(Low pressure side) • Piping D/S of orifice or control valves • Can be found in restricted flow passages(Heat-ex, Venturis, Seals and Impellers)	-	All	Design	VT,UT,RT
Mechanical Fatigue	CS, titanium exhibit an endurance limit- 300 ss, 400 ss, aluminum & non-ferrous alloys, don't exhibit an endurance limit- "calm shell" fingerprint with " beach marks"- cracks initiate	1. Thermal cycling: • Equipment cycles in daily operation-Coke drums. • Continuous s/by equipment-Aux. boilers • Quench nozzle connections such as in water washing systems 2. Mechanical Loading: • Pressure swing absorbers on Hydrogen purification units • Rotating shafts on CF pumps and compressors • Components such as small dia piping • High pressure drop control valves or steam reducing stations can cause serious vibration problems in connected piping	--	All	Design to minimize stress concentrations *	MT, PT
Vibration-Induced Fatigue	A form of mechanical fatigue	• Socket welds are small bore piping at or near to compressors or pumps • Small bore by-pass lines and flow loops around rotating and reciprocating equipment • Small branch connections	---	All	Design	MT, PT*
Refractory Degradation	Damage due to oxidation, sulfidation and other high temp mechanisms	• FCC reactor regenerator vessels, Piping, Cyclones, Slide valves and Internals; In fluid cokers; In Cold shell catalytic reforming reactors • In waste heat boilers and thermal reactors in sulfur plants • Boiler fire boxes and stacks which also use refractories are affected.	--	All Refractories	Design	VT, IR scan
Reheat Cracking	Due to stress relaxation during PWHT @ high temp's- heavy wall sections- intergranular.	• In heavy wall vessels in areas of high restraint including nozzle welds and heavy wall piping • HSLA steels are highly susceptible for cracking.	---	LAS, 300SS, NI-alloys	Design	UT, MT, PT

API 571 Reference Card

Corrosion Mechanism	Description	Affected Unit or Equipment	Temp. Range in °F	Affected metallurgy	Prevention	Inspection Methods
Gaseous oxygen-Enhanced Ignition and combustion	Spontaneous ignition or combustion of metallic and non-metallic components can result in fires and explosions in certain oxygen enriched gaseous environments if not properly designed, operated and maintained. This occurs at low pressures.	• Areas that uses oxygen or enriched air for combustion or other process reasons • SRU, FCCU, Gasification and Partial oxidation units (POX). • Oxygen piping systems especially valves, regulators and other impingement areas are potentially vulnerable. • Nonmetals such as used for seats and seals are easier to ignite than metals.	---	1). CS, LAS-in low pressure oxygen greater than 15psig. With precautions these can be used in High pressure oxygen. 2). 300SS have more resistance to low pressure oxygen and generally difficult to ignite below 200 psig. 3). Cu-Ni alloys are more resistant. 4). Alloy 400 Highly resistant. 5). Al and Ti should not be used.	1. Proper cleaning of the component after Maintenance and Inspection 2. Maintain velocity with in recommended limits(Normally 100ft/s 3. Ensure the suitability of replaced components 4. Use oxygen compatible lubricants 5. Don't open oxygen systems unnecessarily as this could introduce contamination 6. Thorough review of design 7. Minimize sudden changes in the pressure in the system 8. Don't use plastic pipes in the oxygen systems.	• Backlights can be used for check of hydrocarbon contamination • VT
	GENERAL CORROSION MECHANISMS-UNIFORM OR LOCALIZED LOSS OF THICKNESS					
Galvanic Corrosion	1) Electrolyte, 2) anode-cathode, 3) electrical connection- depends on cathode area- coat cathode rather than anode.	Heat ex Normally Tube to Tube sheet different particularly if sea water cooling is utilized Buried pipe lines, Electrical Transmission support towers, ship hulls	--	All	Design*	VT & UT*
Atmospheric corrosion	Marine (20 mpy), humid (1-3) mpy, dry(<1 mpy)	1. Piping and equipment that operates at temperature sufficiently low to allow moisture to present. 2. Poor painting or coating condition 3. Equipment that temperature cycled from ambient to higher or vice versa 4. Equipment idled/ Shutdown for longer periods unless properly mothballed. 5. Tanks and Piping. Pipe that rests on supports entraps water 6. Piers and docks 7. Bimetallic connections	<250	CS, LAS, Copper alloyed Aluminum	Design	VT, UT
CUI CS:10°F to 350°F SS:140°F to 400°F	Pitting damage, loss in thickness-loose flaky scale- carbuncle type pitting	1. Damaged Insulation, Vapor barriers, Weather proofing or mastic or protrusions through the insulations or at insulation termination such as flanges 2. Ping and equipment with damaged / leaking steam tracing etc…. 3. Vibration piping systems, damaged paint locations, Pipe hangers and supports, Valves and fittings, Bolted on pipe shoes, 4. First few feet of a horizontal pipe run adjacent to the bottom of a vertical run.	More severe 212-250,>250 for marine env.	CS, LAS, 300 SS, 400 SS, DUPLEX SS	Appropriate paint coatings, Maintain insulation barriers *	VT, UT, X-Ray profile, neutron backscatter.
Cooling Water corrosion	Fresh water> 140°F, brackish water> 115°F, cause scaling-titanium hydrides >180°F	1. Water cooled heat exchangers and cooling towers in all applications across all industries.	--	All	Design	Lab samples, velocity, U-factor
Boiler Water Condensate	Oxygen scavenging (catalyzed sodium sulfite or hydrazine)-amine inhibitor for CO2 corrosion	1. External treatment system, De-aerating equipment, Feed water lines, Pumps, stage heaters and economizers as well as the Steam generation system on both water and fire sides and the condensate return system.	---	CS, LAS, 300 SS, Copper based alloys	Fe3O4 (magnetite)	Water analysis *
CO2	Corrosion occurs when effluent stream temp drops below dew points (300°F)	1. Boiler feed water and condensate systems in all units 2. Effluent gas streams of the shift converters in H_2 Plant 3. Overhead systems of regenerators in CO_2 removal Plants	<300F	CS, LAS	300ss, 400ss, >12%Cr	VT, UT, RT
Flue-Gas Dew-Point	Sulfuric & forms @ 280°F, hydrochloric acid forms @ 130°F	1. All fired process heaters and boliers that burns fuels containing sulfur 2. HRSG's that have SS300 series feedwater heaters	--	CS, LAS, 300 ss	Design	VT, UT, PT, (300 SS to locate SCC)
Microbiologically Induced Corrosion	Occurs where water is present, stagnant flow-cup shaped pit within pits in CS or subsurface pits in SS	1. Heat Ex., Bottom water of Storage tanks, Piping with stagnant or low flow conditions, Piping in contact with some soils. 2. Equipment with Hydro test water has not been removed 3. Product storage tank and water cooled heat exchangers 4. Fire water systems	--	All	Biocides, Tank internal-coating , U/G-CP	Stream analysis
Soil	Soil resistivity is used to determine corrosivety -external thinning with localized pitting	1. Underground piping and equipment as well buried tank and bottom of storage tanks 2. Ground supported metal structures	---	CS, cast iron, ductile iron	CP, Coating	Measuring Potential *

API 571 Reference Card

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Caustic	Localized grooves	1. Steam generating equipment's and boilers including Heat exchangers 2. Crude unit 3. Pre-heat exchangers, furnace tubes and transfer lines Units that add caustic to remove sulfur from compounds	>175°F, >200°F (very high)	CS, LAS, 300 SS	Design*	UT, RT
De-alloying	Brass become reddish when dealloyed, while cast iron becomes charcoal gray	1. Underground Cast piping when exposed to certain soils 2. Heat exch. Tubing-Brass, Al. Brass 3. Boiler feed water piping system and after boiler components including bronze pumps, monel strainers and brass pressure gage fittings.	<200°F	Copper alloys, Cast iron,Alloy400	CP, coating	Acoustic techniques, Ultrasonic attenuation,MG, UT is N/A
Graphitic	Graphite is cathodic-damage occurs in the presence of moisture or aqueous phase	1. Under ground piping and boiler feed water equipment 2. Fire water systems are particularly vulnerable.	<200°F	Cast iron	Coating	Acoustic techniques, MG, UT is N/A
	HIGH TEMPERATURE CORROSION [400 °F]					
Oxidation	General thinning with an oxide layer covering the surface	1. Fired heaters and boilers	>1000°F - CS >1500 - 300SS	Iron-based alloys	Upgrading more resistant alloy*	UT
Sulfidation	Hydrogen accelerates corrosion- Uniform thinning (localized sometimes)	1. Crude, FCC, Coker, Vacuum, Visbreaker and hydro processing units 2. Boilers and fired heaters exposed to sulfur containing gases Oil fired heaters where oil containing species of sulfur	>500, <500 for copper alloys	Iron, nickel and copper based alloys	Add Cr	UT
Carburization	Requires high carbon-activity gas, low oxygen potential	1. Fired heater tubes 2. Heater tubes in Catalytic reformers and coker units or other heaters where steam or air decoking is performed 3. Ethylene pyrolysis and steam reformer furnaces	>1100F	Iron-based alloys	Lower temp, higher O2&S partial pressure	MG, hardness testing
Decarburization	Requires low carbon-activity gas, CS will be pure iron.	1. Hydro processing units, Catalytic reforming units, Fired heater tubes and pressure vessel components that are hot formed during fabrication.	---	CS, LAS	Add Cr, Mo	FMR, MG, hardness test
Metal Dusting	Preceded by carburization-pits filled with crumbly residue of oxides and carbides in LAS Deep round pits in SS	1. Fired heater tubes, thermo wells and furnace components operating in carburizing environments 2. CRU heater tubes, Coker heaters, Gas turbines, Methanol reforming unit outlet piping and thermal hydro de-alkylation furnaces and reactors.	900-1500	All	No metal is immune-H2S forms protective sulfide layer	VT* ,Heater tubes- Compression wave UT*
Fuel Ash	Contaminants are S, Na,K,V- Molten dissolves oxide layer & 50 Cr-50 Ni more resistant	1. Any fired heater or gas turbine utilizing fuels 2. Fired heaters burning vanadium, and sodium contaminated fuel oils or residue.		All	Injecting special additives	VT
Nitriding	It's rare- Nitrogen diffuses into surface forming needle-like particles of Fe3N and Fe4N hard brittle surface layer – dull gray dry.	1. Steam-methane reformers 2. Steam gas cracking(Olefin plants) 3. Ammonia synthesis plants	Starts>600, severe >900	CS, LAS, 300SS, 400SS	30-80% Ni	Mg, hardness test, VT, magnetism (300SS)
	ENVIRONMENT- ASSISTED CRACKING					
Chloride SSC,	Surface initiated cracks under the combined action of tensile stress, temperature and an aqueous chloride environment.	1. Water cooled condensers 2. Process side of crude tower overhead condensers 3. Drains in hydro processing units 4. Bellows and Instrument tubing, Hydrogen recycle streams containing Cl^-,Boiler drain lines, Insulated 300 series SS lines	>140 F	SS300	Use low chloride water	PT, Phase analysis EC techniques *
Corrosion Fatigue	Initiate @ pits, notches, surface defect. brittle fracture ,Transgranular, ,not branched.	1. Rotating Equipment- Galvanic couples between the impeller and the pump shaft or any pitting due to any corrosion mechanisms will act as stress raiser. 2. Deaerators- Residual fabrication or welding stresses, stress raisers. 3. Cycling boilers: Due to several cold starts, because of differential expansion will lead to crack the magnetite layer will lead to corrosion.	----	All	Design	UT, MTWFMT
Caustic SCC (Embrittlement)	Surface cracks adjacent to non-PWHT- welds- Integranular spider web and filled w/oxides- Transgranular in 300ss-50 to 100 ppm is sufficient for cracking	1. Piping and equipment that handles caustic, including H2S and mercaptanremoval units 2. Sulfuric acid and HF alkylation units, improperly heat traced piping/ equipment, BFW lines, Heat exchanger tubes, Boiler tubes etc…	-----	CS, LAS,300 SS	PWHT, Ni alloys are resistant	WFMT,EC,RT /ACFM,* PT Not Good

API 571 Reference Card

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Ammonia SCC	Copper alloys: aqueous, 8.5 pH, O2, zinc>15%, bluish corrosion product, trans/intergranular cracks—CS- anhydrous ammonium, <.2% water, Air/O2, non PWHT weld or HAZ	1. Cu-Zn alloy tubes in Heat exchangers. 2. Piping and equipment in ammonia refrigeration units, lube oil refining processes, Ammonia storage tanks.	Any range	Copper alloys CS	PWHT CS-300SS, Ni alloys, 90-10/70-30 CuNi are immune-process control	EC- Copper Alloys, CS-WFMT,SWUT & AET
Liquid Metal Embrittlement (LME)	Liquid Metal Embrittlement (LME) is a form of cracking those results when certain molten metals come in contact with specific alloys. Cracking can be very sudden and brittle in nature. Intergranular cracking	1. Location where LME couples are found(SS piping/ vessel in contact with Galv. Steel) 2. LME of Al. Can be found in LNG facilities and Cryogenic gas plants due to condensation of liquid mercury.	300 SS –Zn, Cu Alloys –Mercury, Alloy 400 – Mercury, Al. Alloys – Mercury, HSS-Cd, Lead.	All	Prevented by protecting metal substrates from coming into contact with the low melting metal.	MT,PT
Hydrogen Embrittlement	Loss in ductility-thick walls are more vulnerable as it takes hydrogen more time to diffuse out- cracks are subsurface or surface initiating-intergranular, brittle cracking.	1. CS piping and Vessels in H_2S services in FCC, Hydro processing, Amine, Sour water and HF Alkylation units. 2. Storage spheres made of HSS 3. Bolts and springs made of HSS 4. Cr-Mo reactors, Drums and exchanger shells on Hydro processing units and CRU if Weld HAZ hardness exceeds 235 BHN.	Ambient to 300F; not likely above 160-180F	CS. LAS, 400SS, PH SS, HS Ni alloys	Use lower strength alloys, PWHT	PT, MT,WFMT, RT- Not Good
Ethanol Stress corrosion cracking	1) Surface Initiated cracks, Under the combined action of tensile stress and a fuel grade ethanol (FGE) or gasoline blend environment 2) Dissolved oxygen and presence of variable stresses increase the propensity of cracking. 3) Stresses applied/ residual, Water content 0.1 to 4.5 % vol., Galvanic coupling of new to corroded steel, Cl^- content increase the susceptibility.	1. CS-Storage tanks, Rack piping, and associated equipment. 2. Pipeline used to transport FGE to and from a terminal 3. Equipment handling FGE after blended with gasoline at end use conc. in unleaded gasoline (10%).	--------	All grades of CS	1. Applying PWHT 2. Apply Proper Coating	VT- Not effective since crack is typically tight and filled with corrosion products WFMT-Most effective Shear wave UT-If WFMT not feasible ACFM can be used with less surface preparation than WFMT in areas such as HAZ's. EC-Unproven method.
Sulfate stress corrosion cracking	Surface initiated cracks caused by environmental cracking of Cu alloys in sulfate solutions.	1. Commonly found in Heat exchanger tubes primarily in cooling water services 2. Heat exchanger tube bundles in Overhead distillation systems where sulfate can form at low conc. 3. Crude tower overhead exchangers are best example.	--------	Some Cu alloys especially Admiralty brass-Highly susceptible 70/30, 90/10 Cu alloys are more resistant	Periodic cleaning once in every 5 years Use 90/10 or 70/30 Non Cu based alloys are highly immune.	VT, EC on Heat exch. Tubes Physical bending of tubes to detect shallow cracks in beginning stages.
	GENERAL – UNIFORM OR LOCALIZED LOSS IN THICKNESS PHENOMENA					
Amine corrosion	Amine itself is not corrosive, contaminates are (CO2, H2S, degradation products, HSAS)-CS is suitable for most units- MED, DGA, ADIP, DEA, MDEA-3 TO 6 FPS (rich amine)20 FPS (lean amine)- general thinning (low velocity), localized (high)	1. Amine units, Crude, Coker, FCC, Hydrogen reforming, Hydro processing and tail gas units. 2. Regenerator re-boiler and regenerator 3. Rich amine side of Lean/Rich amine exchangers, hot lean amine piping, Hot rich amine piping, amine solution pumps and reclaimers	>220F	CS	Proper Op's, 300ss, avoid O2 leakage, Avoid HSAS.	VT&UT- Internal Profile RT- External
Ammonium Bisulfide (Alkaline Sour Water)	2% corrosive, 8% highly corrosive- low velocities cause under deposit corrosion,NH4HS salts formed .	1. Hydro processing units(NH_4HS Salts) 2. Air cooler header boxes(Fouling/ Velocity accelerated corrosion) 3. FCC, Sour water stripper, Amine units, delayed coker, (Conc. of NH_4HS)	120-150	CS, Cu alloys brasses	Velocity 10-20fps, resistant alloys(duplex , 825) @ higher velocities	UT, RT
Ammonium Chloride	Occurs in absence of free water @ temp's above Jew pint-Localized pitting-salt have whitish, greenish, brownish appearance	1. Crude tower overheads-Tower top, top trays, overhead piping, exchangers. 2. Hydro processing units, Catalytic reforming, FCCU and coker fractionator overheads and top pump arounds.	>300	All	Ni alloy, Titanium alloys, water wash	UT,RT ,Corrosion Probes
Hydrochloric Acid (HCL)	Associated with dew point corrosion- PH<4.5- oxygen increase corrosion	1. Crude unit, Hydro processing units, CRU	---	All	Proper Op's, Ni alloy, Titanium alloy	UT,RT, Monitoring Ph ,Corrosion probes
High Temp H_2/H_2S	Hydrogen increase corrosion rate compared to high temp Sulfidation-uniform corrosion	1. Hydro processing units-De-sulfurizers, hydrotreaters and hydro cracking units 2. D/S of hydrogen injection points	>500F	All	Add Cr	VT,UT ,RT
Hydrofluoric (HF) Acid	LAS, 300,400ss aren't suitable-CS forms protective fluoride scale-water concentration >3% is corrosive- In CS limit RE=%Cu+%Ni+%Cr=.2 max- Uniform loss for alloy 400 and cracking for non-stress relieved alloy 400	1. Piping and equipment in HF alkylation units 2. HF acid rerun or regenerator tower, Flange faces, dead legs including inlets to relief valves, 3. Condensing overhead vapors in Piping and exchangers on top off isostripper, de-propanizer and HF stripper/ propane stripper. 4. Heat exchanger bundles that heat acid containing streams.	>150F	CS, Cu & Ni alloys	Proper Op's, design, alloy C-276	UT ,RT

API 571 Reference Card

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Naphthenic Acid Corrosion	TAN as low as 0.1 could cause problems- corrosion is severe in mixed flow stream- Localized, pitting	1. Crude and Vacuum heater tubes, Crude and Vacuum transfer lines, 2. Vacuum bottom piping, HVGO and LVGO circuits, HCGO and LCGO circuits. 3. Crude and Vacuum tower internals. 4. D/S of crude and vacuum units and U/S of hydrogen mix points.	>425, severe >750	CS, LAS, 300SS, 400SS,Ni alloy	Add Mo	UT,RT, Hydrogen probes
Phenol (Carbolic Acid)	It's solvent to remove aromatics from lube oil -5 to 15% phenol(dilute) is very corrosive- general or localized corrosion. Best prevented through proper material selection & control of ph solvent chemistry.	Phenol extraction facilities in lube plant	<250F minimal, >450 CS & 304SS	CS, 304ss	316SS, C-276 (High velocities)- Ovhe temp >30F above dew point	UT,RT ,ER Probes
Phosphoric Acid	Catalyst in polymerization units- solid phosphoric acid is not corrosive- may penetrate 0.25" steel in 8 hrs- general or localized	1. Piping and equipment in Polymerization unit where water mixes with catalyst 2. Low velocity areas where there is little or no circulation such as piping manifolds, bottom of kettle type re-boilers, Partial penetration welds, Exchangers where there is sufficient residence time to permit the settling of acid droplets.	<120°F (300ss@100%), <225°F (316ss, alloy 20@85%)	CS,304SS,316SS, Alloy 20	Upgrade metallurgy	UT,RT,ER Probes
Sour Water (Acidic)	H2S decreases pH to 4.5- general, localized pitting-SCC may occur in 300SS.	1. Overhead systems of FCC and coker gas fractionation plants with High H_2S levels and low NH_3 levels.	------	CS	SS,Cu alloys, Ni alloys	UT,RT ,Corrosion Probes
Sulfuric Acid	Affect CS-HAZ- Severe corrosion in CS@>3FPS and/or >65% concentration, General corrosion	1. Sulfuric acid alkylation units including reactor effluent lines, re-boilers, deisobutanizer overhead systems and the caustic treating section 2. Bottom of fractionation towers and re-boilers.	---------	All	Ni alloys	RT,UT, ER probes
	GENERAL- ENVIRONMENT-ASSISTED CRACKING					
Polythionic acid Stress CC (PASCC)	Occurs during shutdowns, startups, when exposed to air& moisture-HAZ "L grade SS is less susceptible to sensitization- Intergranular cracks."	1. Heat exchanger tubes, furnace tubes and piping 2. FCC units, Hydro processing units, Crude and coker units, Boilers and high temperature equipment exposed to sulfur containing combustion products	750°F-1500°F for sensitization	Sensitize austenitic steels	Use chemically stable steel (321ss, 347, alloy 825 and alloy625)	PT
Amine Stress CC	Occurs in lean amines- MEA, DEA mainly- concentration is not a factor- initiate ID on welds (transverse or longitudinal) or adjacent to HAZ- Intergranular and filled with oxides	1. All Non-PWHT piping and equipments in lean amine service including contactors, absorbers, strippers, regenerators, and heat exchangers as well as equipment subject to amine carry over.	>ambient		PWHT, Resistant alloys	ACFM/WFMT, PT(not good)*
Wet H2S Damage (Blistering/HIC/SOHIC /SSC)	Caused by atomic hydrogen. H_2 is formed due to corrosion.	1. In hydro processing units- Increasing conc. of above 2% of Amm.Bisulfide increase potential of Blistering, HIC and SOHIC 2. Presence of CN^- Vapor recovery section of FCC and Delayed coking units, Fractionator OH drum, Fractionation towers, Compressor Interstage separators, KO drums HExs, Condensers and Coolers. Sour water stripper and amine regenerator OH systems 3. SSC is mostly found in hard weld and HAZs in high strength components including bolts, RV springs, 400 series SS valve trim, Compressor shafts, sleeves and springs.	<180°F	CS, LAS	Process (pH, H2S below 50, wash water, ammonia &cyanides concentrations- PWHT	Focus on weld seam and nozzles-VT, WFMT, EC, RT/ACFM* SWUT- Volumetric inspection & crack sizing *
Hydrogen Stress Cracking- HF	Results by exposure to aqueous HF acid environment- HAZ- Interganular- use CS with Carbon equivalent (CE) <0.43		---		PWHT, Resistant alloys	WFMT, Hardness testing
Carbonate Stress Corrosion Cracking	Susceptibility increases with pH and carbonate concentration- Propagate parallel to welds, weld deposits, HAZ- Intergranular and filled with oxides	1. FCC Unit-Main fractionator OH condensing and reflux system, D/S wet gas compression system, Sour water emanating system.Both piping and equipment 2. Sour water stripping units of side pump around type in the pumparound return line to the SWS tower; on the OD process side of highly cold worked SA-179 Condenser tube U-bends. 3. Piping and equipment in KCO_3 in catacarb and CO_2 removal facilities of Hydrogen manufacturing units.	>200°F		PWHT, Resistant alloy	WFMT, SWUT

API 571 Reference Card

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	GENERAL- OTHER MECHANISMS					
HTHA	Exposure to hydrogen at elevated temperatures and pressures- H reacts with carbides to form methane-300ss and >5Cr are not susceptible to HTHA- may cause decarburization- Intergranular with blistering sometimes.	1. Hydro processing units such as hydro treaters(De-sulfirizers) and hydro crackers, Catalytic reformers, Hydrogen producing units and hydrogen cleanup units such as pressure swing absorption units 2. Boiler tubes in very high pressure steam service	---	CS, C-Mo, Cr-Mo	Add Cr&Mo	UT techniques
Titanium hydriding	Hydrogen diffuses into titanium to form hydride (brittle)- PH<3, PH>8	1. Primarily in SWS(Sour water strippers and amine units in OH Condensers, Heat exch. Tubes, Piping and other titanium equipment operating above 165°F 2. Hydrogen atmospheres at about greater than 350°F especially in the absence of moisture or O_2. 3. Cathodically protected equipment with protection potentials < -0.9v SCE	>165°F, > 350°F in hydrogen atmosphere.	Titanium alloys	Avoid titanium alloys in hydriding services	EC Techniques